

SPICAM ON MARS EXPRESS: THE ATMOSPHERE OF MARS FROM TOP TO BOTTOM

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Introduction:

SPICAM Light, a light-weight (4.7 kg) UV-IR instrument to be flown on Mars Express orbiter, is dedicated to recover most of the science that was lost with the demise of Mars 96, where the SPICAM set of sensors was focused on atmospheric studies (SPectroscopy for the Investigation of the Characteristics of the Atmosphere of Mars). The new configuration of SPICAM Light includes an optical sensor (3.8 kg) and an electronics block (0.9 kg). The optical sensor consists of two channels. A UV spectrometer (118 - 320 nm, resolution 0.8 nm) is dedicated to nadir viewing, limb viewing and vertical profiling by stellar and solar occultation. It addresses key issues about ozone, its coupling with H₂O, aerosols, atmospheric vertical temperature structure and ionospheric studies. An IR spectrometer (1.0-1.7 μm, resolution 0.5-1.2 nm) is dedicated primarily to nadir measurements of H₂O abundances, and to vertical profiling during solar occultation of H₂O and aerosols. A simple data processing unit (DPU, 0.9 kg) provides the interface of these channels with the spacecraft. The optical scheme of both channels is indicated on Figure 1.

In nadir orientation, SPICAM UV is essentially an ozone detector, measuring the strongest O₃ absorption band at 250 nm in the spectrum of the solar light scattered back from the ground (Figure 3). In the stellar occultation mode the UV Sensor will measure

the vertical profiles of CO₂, temperature, O₃, clouds and aerosols (figure 7). The density/temperature profiles obtained with SPICAM Light will constrain and aid in the development of the meteorological and dynamical atmospheric models, from the surface to 160 km in the atmosphere. This is essential for future missions that will rely on aerocapture and aerobraking. UV observations of the upper atmosphere will allow studies of the ionosphere through the emissions of CO, CO⁺, and CO₂⁺, and its direct interaction with the solar wind. Also, it will allow a better understanding of escape mechanisms and estimates of their magnitude, crucial for insight into the long-term evolution of the atmosphere. The SPICAM Light near-IR sensor employs a pioneering technology acousto-optical tuneable filter (AOTF), and it is dedicated to the measurement of water vapour column abundance in the IR simultaneously with ozone measured in the UV, in the Nadir orientation. In solar occultation mode this channel permits to study the vertical structure of H₂O, CO₂, and aerosols.

The instrument is built in cooperation between Service d'Aéronomie/IPSL in France, BISA in Belgium, and IKI in Moscow. Co-investigators are the authors of Bertaux et al (2000).

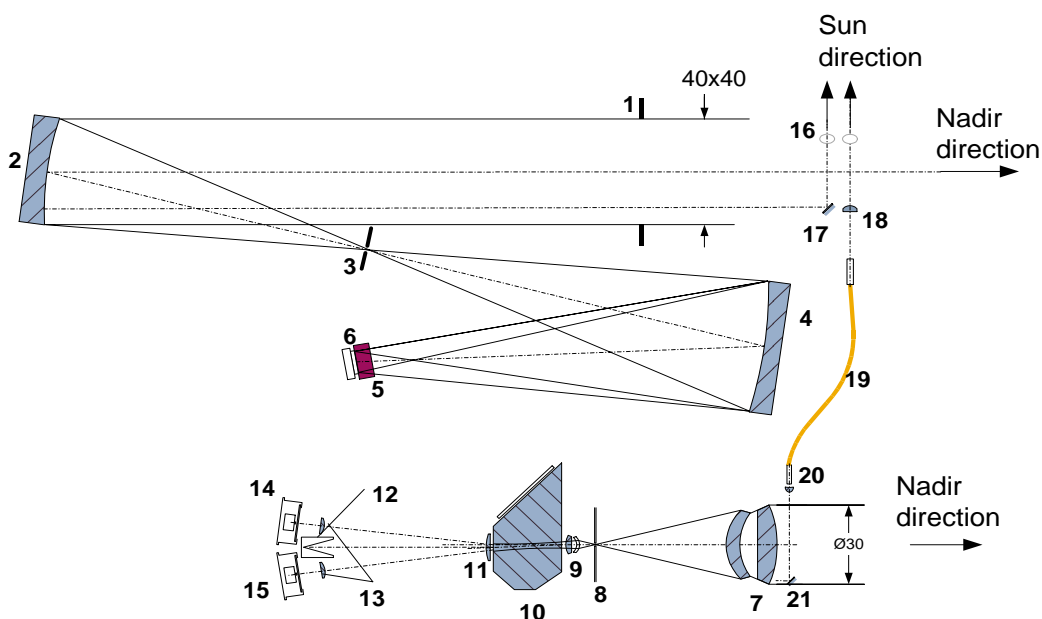


Figure 1. Optical scheme of the UV and IR channels of SPICAM Light. 1- aperture blend of the UV channel; 2- off-axis parabolic mirror; 3- slit (can be changed from wide to narrow, by a mechanical actuator); 4- concave UV grating; 5- intensifier; 6- CCD; 7- IR channel objective; 8- IR FOV diaphragm; 9, 11- collimating lenses; 10- AOTF crystal; 12- light trap for undiffracted light; 13- detector proximity lenses; 14- “extraordinary” beam detector; 15- “ordinary” beam detector; 16- solar opening (closed by shutter when not looking to the Sun); 17, 21- flat mirror; 18- IR solar entry; 19- optical fibre; 20- fibre collimator.

Nadir mode viewing. In this mode, used mostly around pericenter, SPICAM is oriented towards the nadir, like the other optical instruments (PFS,OMEGA, HRSC camera), and UV and IR spectra of the backscattered solar light are recorded along the track at a rate of one per second. Figures 2, 3, 4 give an idea of the shape of the albedo spectra that will be recorded by SPICAM. Actually, the level of the albedo is of course below 1, and its value is dependent on the quantity of aerosols and their optical properties in the atmosphere of Mars (Fedorova, private communication, 2002). The AOTF system is such that a certain number of wavelength micro windows may be selected and scanned , according to a careful selection of various modes (for instance, around the water vapour band). New modes may also be introduced by telecommand.

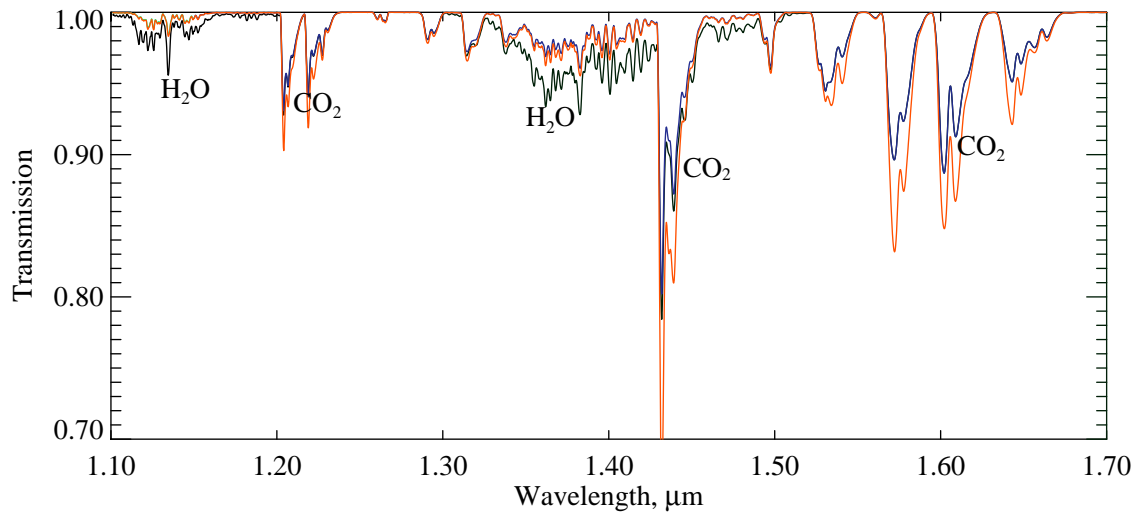


Figure 2. Line-by-line spectra of atmospheric transmission in Nadir. Spectra are computed for a water vapour abundance of 15 and 50 pr. μm (offset in H_2O bands) and for surface pressures of 6 and 7 mbar (offset in CO_2 bands). This wavelength domain is the very one used by MAWD experiment on board Viking orbiters.

atm. A possible effect of H_2O_2 is considered: no H_2O_2 (curve a); H_2O_2 column of $2 \cdot 10^{16} \text{ cm}^{-2}$ (curve b) and $2 \cdot 10^{17} \text{ cm}^{-2}$ (curve c).

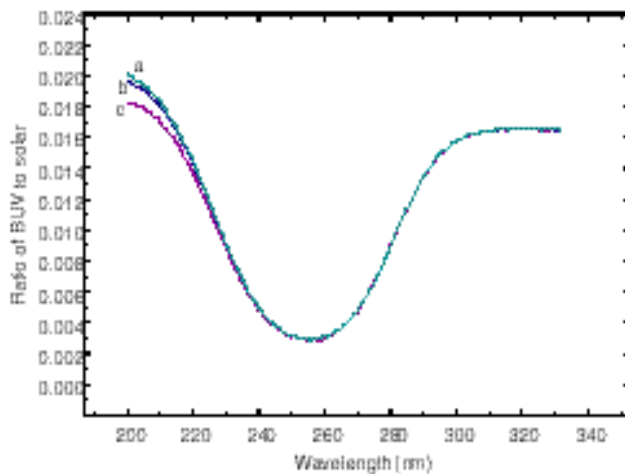


Figure 3. Modtran computations for nadir geometry. Solar zenith angle 60° , ozone total abundance $5 \mu\text{m}$ -

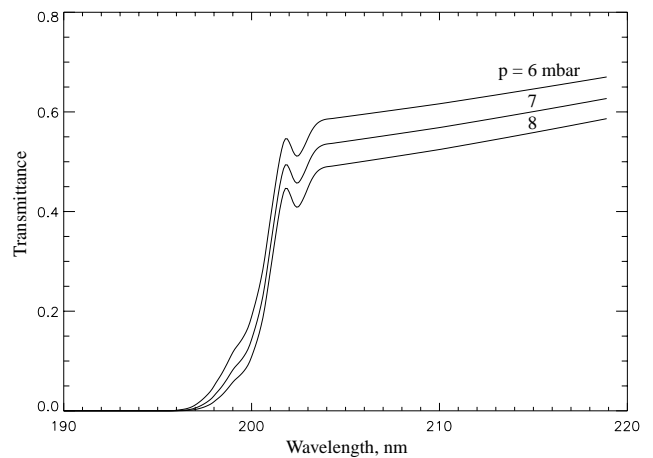


Figure 4. Modification in UV transmission spectrum in nadir configuration with surface pressure. There is

the possibility to determine the surface pressure, from the wavelength cut-off around 200 nm of the UV albedo of Mars atmosphere+ground.

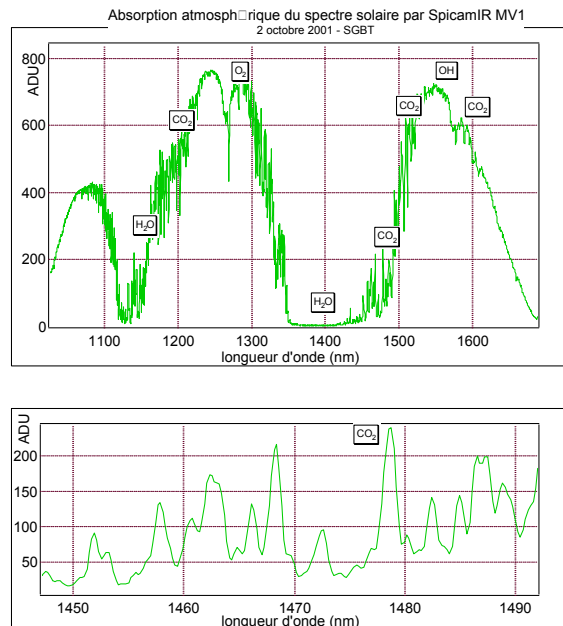


Figure 5. Spectrum of solar light scattered by the parking lot of Service d'Aéronomie as measured by the AOTF channel. All recognized atmospheric absorptions are indicated.

Occultation measurements.

The instrument may also work in the solar or stellar occultation mode. In this mode, the whole Mars Express spacecraft is oriented and maintained with the SICAM FOV pointing (open loop) to a star or to the sun. Then, the orbital drift makes the line of sight penetrating more and more deeply in the atmosphere of Mars, down to total occultation. The stellar occultation technique offers three decisive features:

- an absolute concentration derived from a relative measurement (no need of instrument calibration, self calibrated method)
- excellent vertical resolution, whatever is the distance to the planet (because the star is a point source)
- the accuracy of altitude knowledge, at variance with limb emission methods, is independent of the attitude of the spacecraft. The LOS is entirely determined by the direction of the star in the sky (known) and the position of the S/C on its orbit.

Stellar occultations will be done preferably on the night side of the orbit, and will not affect the operation of dayside mapping instruments. SPICAM will measure the vertical distribution of CO₂, tempera-

ture, O₃, aerosols, O₂ and possibly H₂O₂ by using the technique of stellar occultation. Solar occultations are also possible at various periods of the mission (figure 6). Several or at least one occultation per orbit (3 per day) are foreseen, the limiting factor being the spacecraft orientation as a resource to be shared between the various experiments. For solar occultation, the IR channel is also activated to retrieve H₂O vertical profile with a high accuracy. A lateral viewport of SPICAM is used in this mode, in order to avoid solar light entering the FOV of the other optical instruments.

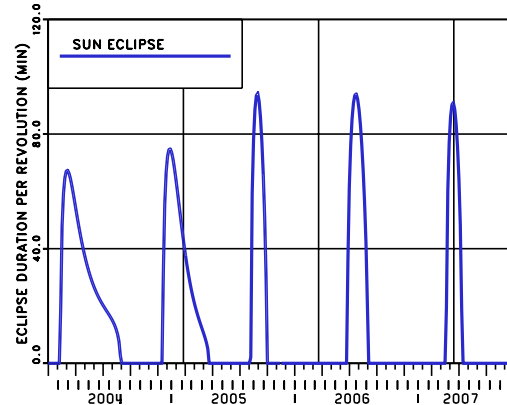


Figure 6. Periods of solar eclipse at orbit G3A. (Figure adopted from Hechler and Yanes, 1999.)

Because the CO₂ cross-section presents an enormous dynamic range in the UV, the CO₂ absorption may be detected already at an altitude of 150 km. For decreasing tangential heights, the CO₂ manifests itself (figure 6) by a sharp cut-off which increases in wavelength, up to 200 nm at $z=10$ km. Longward of 200 nm, the transmission spectrum is dominated by dust and CO₂ Rayleigh extinction, with the additional trough at 255 nm due to ozone. The depth of this trough is a direct measure of ozone line density. From the given S/N in stellar occultation mode, the O₃ line density N_h accuracy will depend on the UV magnitude of the star. From extensive simulations (Korablev, Bertaux and Dubois, 2001) it can be estimated that the accuracy on the O₃ line density will be about 2% for about 20 stars in the sky and the measuring threshold corresponding to an absorption of 1%, corresponds to $N_h = 10^{15}$ mol.cm⁻² (horizontal) and local density of $3.5 \cdot 10^7$ cm⁻³ at all altitudes $z > 15$ km.

The Rayleigh extinction above 200 nm can be computed from the CO₂ line density determined below 200 nm, and the remaining continuous absorption above 200 nm may be attributed to dust/aerosol for a determination of its vertical distribution and spectral characteristics in the UV.

CO₂ density and temperature profile

Once the line density of CO₂ is determined from the transmission spectra, the local density $n(z)$ is deter-

mined from an Abel inversion. Then, the hydrostatic equation allows temperature to be determined. As for O_3 , the accuracy on the CO_2 line density will be about 2% for 20 stars. The accuracy of retrieved temperature is estimated to be ± 3 K in the whole range of altitude, starting at 130-160 km at top level, while the lowest altitude achieved will depend on the absorption by aerosols or clouds, and most likely located between 5 and 20 km.

In addition, these simulations have shown that O_2 may be retrieved, with the current estimate of 0.1% mixing ratio. This would be the first time that O_2 is systematically measured in the atmosphere of Mars.

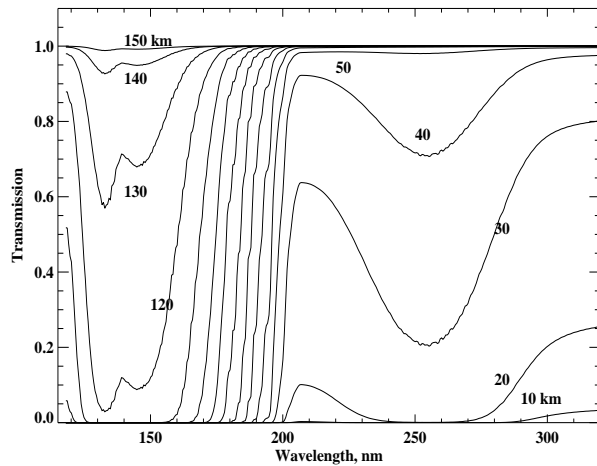


Figure 7. Simulated transmission spectra in stellar occultation geometry for tangential altitudes from 150 to 10 km with the step of 10 km.

Airglow observations at the limb

Study of the ionosphere from UV

Most of the ionosphere lies below the nominal pericenter altitude of Mars Express (300 km) and unfortunately in-situ measurements will be

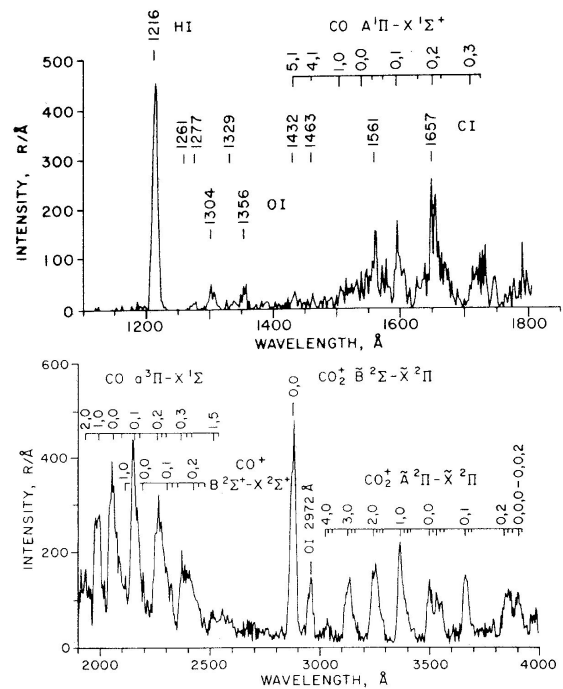


Figure 8 Mariner 6 and 7 ultraviolet spectrum of the upper atmosphere of Mars at a resolution of 20 Å. Spectrum at the limb at an altitude between 140 and 180 km, and includes four individual observations (Figure adopted from Barth et al., 1971).

impossible. However, the natural UV airglow of the atmosphere offers a definite possibility to study by remote sensing the ionosphere and its temporal behaviour as a function of solar-wind parameters. Figure 14 shows the spectrum of dayglow recorded by Mariner 6 and 7 UV spectrometer (Barth et al., 1971). The main ionisable neutral constituent is CO_2 , and the CO_2^+ transition ($B^2\Sigma^u+ - X^2\Pi_g$) at 289 nm (or 2890 Å) is produced by photoionisation of CO_2 from solar UV at $\lambda < 69$ nm. The other band CO_2^+ ($A^2\Sigma_u - X^2\Pi_g$) between 300 and 400 nm is produced by a combination of photoionisation and fluorescence scattering on CO_2^+ ions. The SPICAM UV long wavelength cut-off is at 320 nm, which is enough to measure the (4,0) and (3,0) transitions of the A-X band.

O_2 airglow on the limb in the IR

Recently, a dayglow at 1.27 μm $O_2(^1\Delta_g)$ emission was observed, and mapping of this emission is reported by Krasnopolsky and Bjoracker (2000). The predicted signal-to-noise ratio for SPICAM will be superior to 20 in a single spectral bin, or 200-300 for the entire band.

Conclusion: The measurements of SPICAM will take their full power when compared and analyzed in the context of various models, for the benefit of these

models: a photo-chemistry model (in development by Franck Lefèvre at Service d'Aéronomie) , a GCM model of the atmosphere , extended to the thermosphere, and a model of the ionosphere.

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